

## **MANUFACTURING RESOURCE PLANNING (MRP/MRP II)**

*by Joe M. Carter, PhD*

As stated in DoDD 5000.1, "the primary objective of the defense acquisition system is to acquire quality products ....., in a timely manner, at a fair and reasonable price." It further describes management controls as an integral system for assuring effective and efficient acquisition.

"Rigorous internal management control systems are integral to effective and accountable program management. The objective is to perform acquisition functions efficiently and effectively while maximizing the utilization and protection of resources through internal management controls." DoDD 5000.1

In manufacturing complex weapon systems (or any other product), the production line must bring together the right quantity of subassemblies and components at the right time to insure delivery in a timely manner (i.e. delivery schedule is met). A company utilizes a materials management system to control the schedule for ordering and producing material. Therefore, knowledge of materials management is imperative to understanding manufacturing systems.

### **Materials Management and Accounting System (MMAS)**

A contractor's ability to meet the production contract schedule is totally dependent upon the effective operation of his production control system. In addition, the governments use of progress payments provides an added source of risk relative to work-in-process inventories. For these reasons, the DOD has implemented a set of guidelines that should be met by a contractor's MMAS. Contractor systems that meet these guidelines should be able to provide defense materiel in a timely manner at minimal risk to the government.

DOD guidelines for an MMAS are provided in DFAR 242.7206. The contract requirements for an MMAS are provided in DFAR 252.242-7004 (see appendix to this document). DLAD 5000.2, Contract Management, (see appendix) provides specific guidance for reviewing a contractor's MMAS. In general, the contractors system must:

- (i) Reasonably forecasts material requirements;
- (ii) Ensures that costs of purchased and fabricated material charged or allocated to a contract are based on valid time-phased requirements; and
- (iii) Maintains a consistent, equitable, and unbiased logic for costing of material transactions.

In assessing the ability of a contractors MMAS system to perform these functions at minimal risk to the government, the DOD has established 10 guidelines, known as the MMAS standards (see appendix). For large contracts, DOD personnel are tasked with reviewing a contractors MMAS system to assess its ability to meet these guidelines. To perform this task, government personnel must be familiar with modern production management (aka: material management) concepts and systems. The remainder of this document will attempt to provide a brief overview of modern production management concepts and remove some of the mystique and misconceptions about Just-in-Time (JIT) manufacturing.

## Materials Management

Materials management is concerned with providing answers for two questions:

- When should I order/manufacture this item?, and
- How much of this item should I order/manufacture?

These questions must be answered such that an optimum balance is achieved between two competing objectives. These objectives are, to minimize investment in inventory, and to meet the customer's demand for the product. Numerous materials management systems have been developed to accomplish these objectives. The type of system to use depends on the pattern of demand and the customer service level that is desired.

Demand patterns can be classified into two broad categories, independent and dependent. Independent demand exists when there is no relationship between the demand for the item and any other item. In other words, the demand depends on customer orders or purchases. This type of demand exists in retail stores, warehouse operations, and for end items in manufacturing. It is also the type of demand that is dealt with by the DOD spare parts program. Dependent demand refers to a demand pattern whereby the demand for the item is directly related to the demand for another item. In manufacturing, the requirements for subassemblies, components, and raw materials is totally dependent on the demand for the end item.

### Order Point Systems

Various materials management systems have been devised to handle independent demand patterns. The easiest to understand is the classical Economic Order Quantity (EOQ) model, which is commonly used by retail stores. The EOQ systems attempt to minimize the total inventory cost that is the sum of the ordering cost and the holding cost. The ordering cost is all cost involved with placing an order, which is primarily administrative. The holding cost is the cost involved with having excess inventory. This includes: warehouse cost, obsolescence cost, spoilage cost, and the interest that could be earned if the equivalent money were invested elsewhere. Figure 1 graphically depicts the inventory level in a simple EOQ system. Whenever the stock on hand reaches the reorder point level,  $r$ , an order is placed for a quantity,  $Q$ , of the item. Assuming a constant demand and constant lead-time for delivery, the order would arrive simultaneously with the inventory position reaching zero.

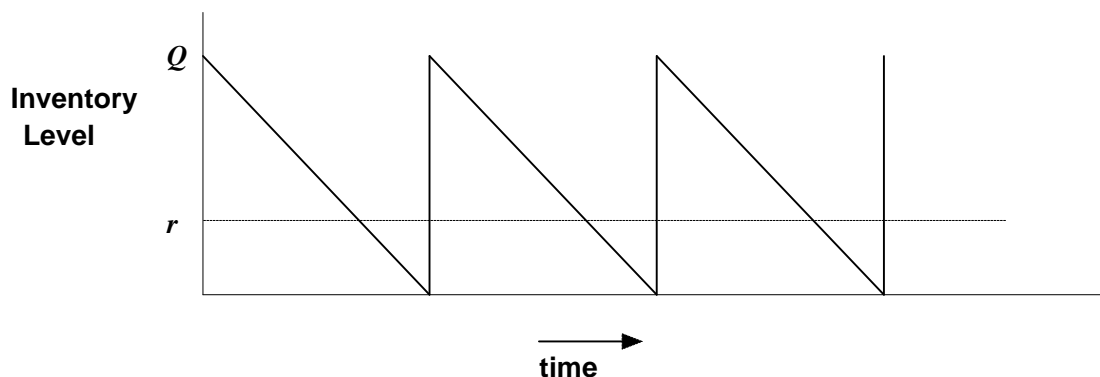
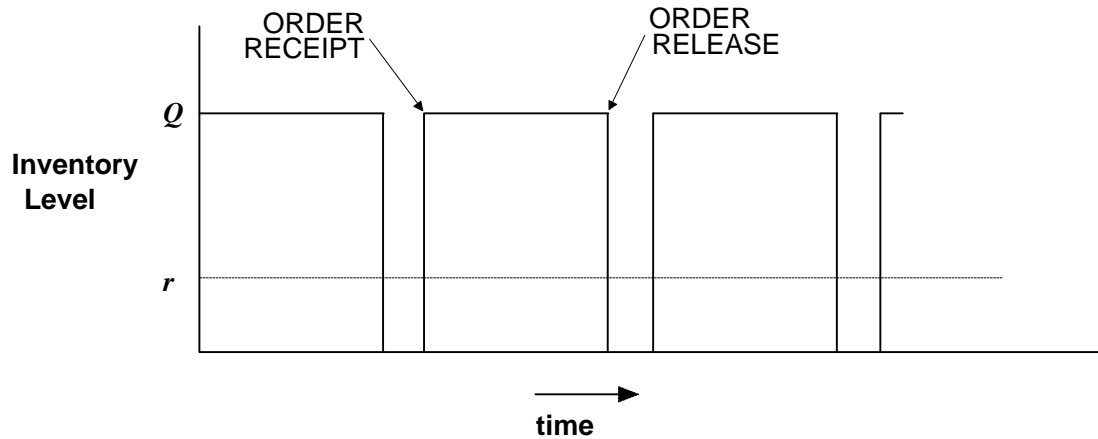


Figure 1 -- Classical EOQ Model



**Figure 2 -- Dependent Demand Using EOQ Model [4]**

Assuming a constant demand and lead-time, the optimal values for the order quantity and reorder point can be calculated as [4]:

$$Q = \sqrt{\frac{2 \cdot C \cdot R}{H}}, \text{ and } r = \frac{R \cdot L}{52}$$

where,  $Q$  = economic order quantity,  $C$  = order/setup cost per order,  
 $R$  = annual demand in units,  $H$  = holding cost per unit per year,  
 $r$  = reorder point, and  $L$  = lead-time in weeks.

More advanced formulations of this model have been developed to handle special requirements, such as: backordering, sales prices, quantity discounts, service levels, variable demand patterns, and variable lead-time. Computerized systems are available to automatically handle the material accounting and ordering based upon the desired parameters of the system.

### **Materials Requirement Planning (MRP)**

The materials management problem in a manufacturing operation is slightly different than in retail sales. In retail sales, we can assume inventory is gradually depleted and we can describe that depletion rate as a constant or with some statistical distribution. In manufacturing, all the inventory necessary to fulfill a production order is released to production with the order release. It may be weeks, months, or years before another order for this item is received. This is known as a "lumpy" demand pattern and is graphically depicted in Figure 2. Because the basic assumptions for the classical EOQ model are not met, using an EOQ system for subassemblies, components, and raw materials in manufacturing will cause excessive stockage of material; thereby creating a non-optimal situation.

For dependent demand patterns (i.e. "lumpy"), a MRP based system is the best to use. A MRP system converts the master production schedule for end items into a detailed schedule for the release of purchase request or production orders. MRP is based upon the fact that the demand for subassemblies, components, and raw material is directly dependent on the end item. The end item requirement is determined by customer demand (firm orders or forecast).

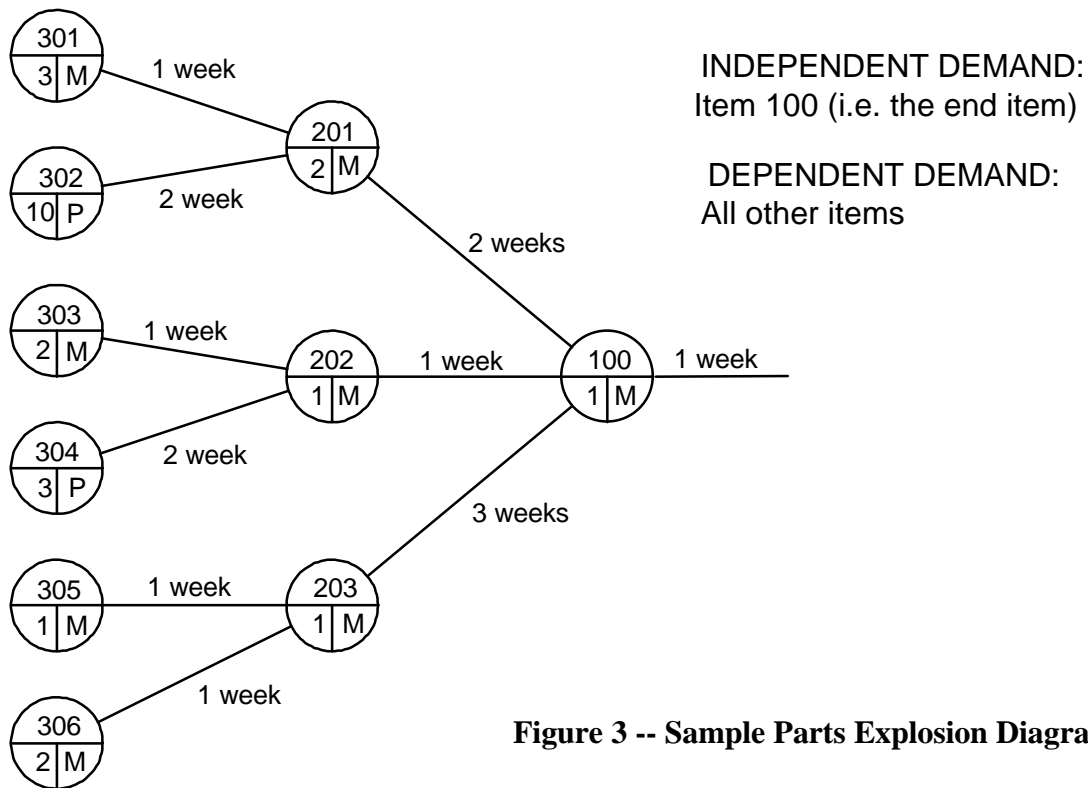
A MRP system is composed of three elements: a Bill-of-Materials, the Master Production Schedule (MPS), and physical inventory records. The bill-of-materials is a listing of all the components that go into the final end item. There are various ways of depicting the bill-of-materials. In this paper, we will use a parts explosion diagram to graphically show the relationship among all parts. A sample diagram is shown in Figure 3. For each item, the diagram displays four pieces of information:

- the item number (top of circle),
- the quantity of items required in the next higher assembly (lower left of circle),
- whether the item is made in-house (M) or purchased (P) (lower right of circle), and
- the lead-time for purchase or manufacture of the item (line leading out of the circle).

The second element of a MRP system is the Master Production Schedule (MPS). The MPS uses knowledge of customer demand and current stock position, to create a production schedule for each end item produced at the plant. Since this schedule is for END ITEMS, which are independent demand, the EOQ type materials management should be used to determine optimal lot sizes. A sample MPS for item # 100 (see Figure 3) is given in Table I.

In this example, the current date is 31 Dec and we have a stock of 40 item # 100's. Considering the forecast and firm orders for Jan, we have enough stock to cover customer demand.

Therefore, we do not plan to build any of these items in January and should have 20 items remaining. In Feb, we anticipate a customer demand for 20 items (5 forecasted and 15 firm orders). Again, we have enough stock on hand to cover the demand. In March, we anticipate a customer demand for 25 items. Since we do not have the stock to cover this demand, we must build these items. The question is, how much do we build? Lets assume that the EOQ model tells us to build 60 each time we manufacture this item. Therefore, we build 60 in March and anticipate having 35 remaining at the end of March. Hopefully, you can trace through the remainder of the schedule.



**Figure 3 -- Sample Parts Explosion Diagram**

Some people consider MRP a push system because the MPS causes orders for the end item to be released based on forecast demand in lieu of actual demand. This is contrasted to a pull system that only builds product to meet customer demand. Let's investigate this theory. In the sample MPS, notice that the majority of the customer demand in January and February emanates from firm orders. As we go further into the future, the majority of the demand is from forecast. This seems to support the theory that MRP is a push system. However, in an MRP system, the MPS is updated at least monthly. For our example, if at the end of January, the forecasted orders for February, March and maybe April have not materialized into firm orders, then the MPS would be adjusted to reflect this change. Thus, it is not a true push system. It is true that some long lead-time items may be manufactured based on forecast demand. But, if these long lead-time items were not available, it is unlikely that we could ever meet a customer's demand schedule. For DOD contractors, their MRP systems will seldom be push type systems because DOD provides a firm delivery schedule with contract award. The MPS for the end item will simply reflect this delivery schedule.

The final element of an MRP system is the Inventory Record. This is simply a computer file that keeps track of the current stockage of each item, number of items currently being built, number of items on order, and anticipated delivery date. This information is not only kept for end items, but all components.

<p style="text-align: center;"><b>TABLE I</b> <b>Sample Master Production Schedule</b></p>													
Current Date: 31 Dec	MONTH												
Item #: 100	D	J	F	M	A	M	J	J	A	S	O	N	D
Forecast		0	5	10	20	20	20	20	20	20	20	20	20
Firm Orders		20	15	15	5	0	0	0	0	0	0	0	0
Begin Stock		40	20	0	35	10	50	30	10	50	30	10	50
Produce		0	0	60	0	60	0	0	60	0	0	60	0
End Stock	40	20	0	35	10	50	30	10	50	30	10	50	30

So far, our MRP system has only taken care of scheduling the end item. If we review Figure 3, we see that all the other items are dependent demand (i.e. the requirements for these items depends on item # 100). We also see that the lead-times require that these items be produced several weeks prior to the production of item # 100. What we need is a systematic process to determine when to release production orders or purchase request which will assure that these items are available to the manufacturing lines at the right time and in the right quantities. Sounds like we need something similar to the projected LOB discussed earlier.

### How MRP Works

Remember that a materials management system must tell when and how much of each item to purchase or build. Therefore, the MRP system must translate the MPS for the end item into build/buy schedules for each subassembly, component, and raw material. In most MRP systems, these schedules are developed weekly. Therefore, the first step is to transform the monthly MPS into weekly requirements. In our example, 60 items (recall that this was the EOQ) must be built during March. For simplicity sake, let's assume that the production of these items will be equally distributed throughout the month (i.e. 15 per week). In an MRP system, this is known as the gross weekly requirements and reflects the number of items that must be completed by the end of the week. In Figure 3 we see that item 100 takes a week to build. Therefore, the work order must be released to production one week earlier.

All MRP systems utilize a MRP table to assist in determining when to release work orders or purchase orders. The MRP table for item 100 to support our MPS is shown in Table II(a). The Gross Requirements line indicates that the 25 items required by the MPS will be produced during the first two weeks of March. The Scheduled Receipts line shows the equal distribution of the production of all 60 items during the month. The On-Hand line can easily be calculated by:

$$\text{On-Hand}_{\text{current period}} = \text{On-Hand}_{\text{prior period}} + \text{Receipts}_{\text{current period}} - \text{Reqmt's}_{\text{current period}}$$

For example, at the end of week 5 there are zero items on-hand. During week 6, 15 items are received from production (scheduled receipts line), but 10 are shipped to the customer (gross requirements line). This leaves five items on-hand at the end of week 6. Numerically, this is:

$$\text{On-Hand}_6 = 0 + 15 - 10 = 5.$$

Since the production of any item takes time, the Planned Order Release line is the same as the Scheduled Receipts line offset by the lead-time. This indicates a work order for the first 15 items must be released to production during the 4<sup>th</sup> week of February in order to be available to meet the gross requirements for the first week in March.

All other items in Figure 3 (item 201 thru 306) must be produced or procured to meet the production schedule for item 100. Table II(b) shows the development of a MRP table for item 201. For each item 100, we must have two item 201's (see Figure 3). The gross requirements for any dependent demand item is determined by the next higher assembly. Since 15 item 100's will be built during period 4 (lets assume the order release is at the beginning of the week), we must have at least 30 item 201's during period 4. Therefore, the gross requirements for item 201 in period 4 is 30. The same is true for periods 5, 6, and 7. For now, lets assume that we are going to schedule the receipts of this item to coincide exactly with the gross requirements. Thus, the scheduled receipts line is identical with the gross requirements line. Since the lead-time for item 201 is 2 weeks, the planned order release will be offset by 2 weeks from the scheduled receipts line.

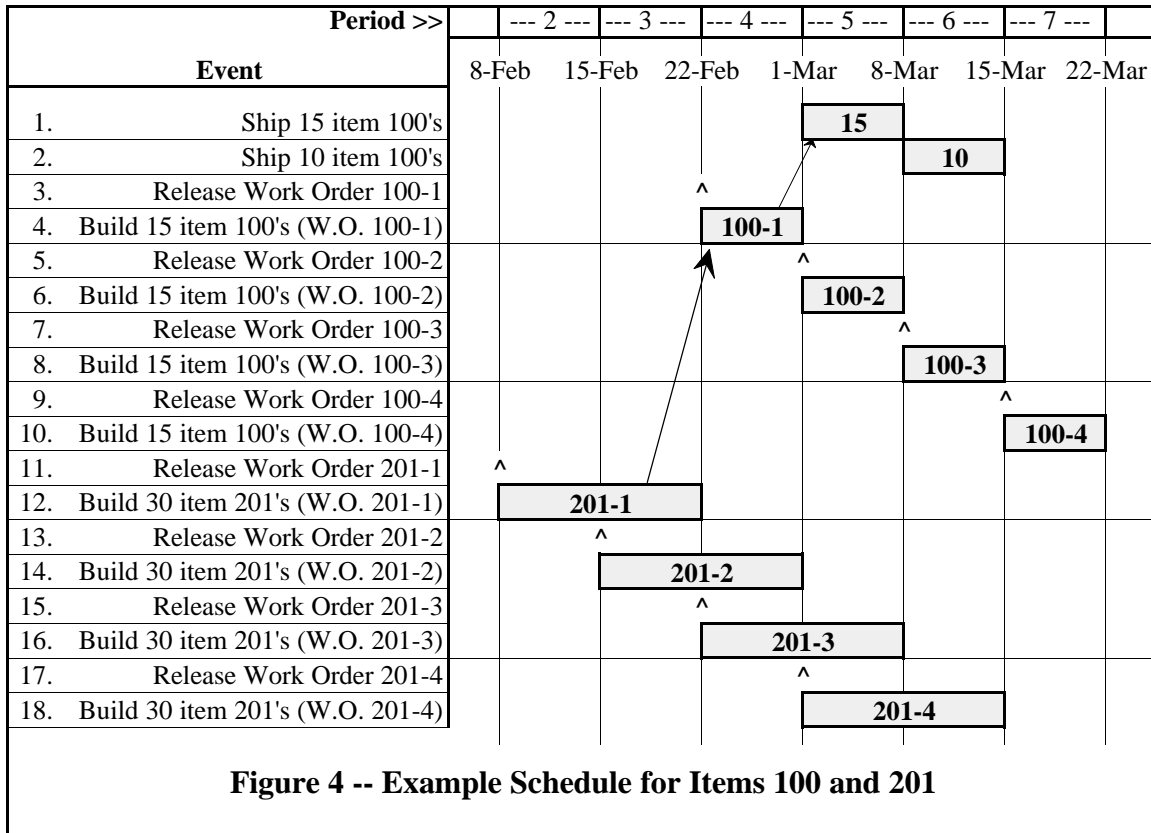
These dates and numbers may be getting a little confusing. So lets look at the planned production/ship schedule for items 100 and 201 to see how these items are being scheduled. Figure 4 provides a snapshot of the planned schedule for these two items. Line 11 and 12 reflect the release and production of the first work order for item 201 (W.O. 201-1). These items will support the release and production of the first work order for item 100 (W.O. 100-1). These items will be the 15 items shipped during the week of 1 March. We can see the same type of schedule for each of the other work orders. Notice that immediately upon completion of a work order for item 201, these items are released to production of item 100, and immediately upon completion of item 100, these items are shipped. Therefore, this schedule does not allow any on-hand to accumulate for either item. This does not mean there is zero WIP. But, all WIP is currently being consumed into the next higher assembly.

By following the same logic as used for item 201, a MRP table for item 301 is provided in Table II(c). See if you can trace how each of these values was determined.

**TABLE II**  
**Example MRP Tables**

ITEM: 100 (the end item) (a)									
Period (aka: time bucket)	0	1 Feb 1	2	3	4	1 Mar 5	6	7	8
Gross Reqmt's		0	0	0	0	15	10	0	0
Scheduled Receipts		0	0	0	0	15	15	15	15
On hand	0	0	0	0	0	0	5	20	35
Plan'd Order Release		0	0	0	15	15	15	15	0
ITEM: 201 (assuming lot-by-lot scheduling) (b)									
Period (aka: time bucket)	0	1 Feb 1	2	3	4	1 Mar 5	6	7	8
Gross Reqmt's		0	0	0	30	30	30	30	0
Scheduled Receipts		0	0	0	30	30	30	30	0
On hand	0	0	0	0	0	0	0	0	0
Plan'd Order Release		0	30	30	30	30	0	0	0
ITEM: 301 (assuming lot-by-lot scheduling) (c)									
Period (aka: time bucket)	0	1 Feb 1	2	3	4	1 Mar 5	6	7	8
Gross Reqmt's		0	90	90	90	90	0	0	0
Scheduled Receipts		0	90	90	90	90	0	0	0
On hand	0	0	0	0	0	0	0	0	0
Plan'd Order Release		90	90	90	90	0	0	0	0
ITEM: 301 (assuming POQ = 3 weeks) (d)									
Period (aka: time bucket)	0	1 Feb 1	2	3	4	1 Mar 5	6	7	8
Gross Reqmt's		0	90	90	90	90	0	0	0
Scheduled Receipts		0	270	0	0	90	0	0	0
On hand	0	0	180	90	0	0	0	0	0
Plan'd Order Release		270	0	0	90	0	0	0	0





Notice that in Tables II(b) and (c) there is never any stockage on-hand at the end of the week. This is because we have used what is called a "lot-by-lot" ordering technique. There are numerous techniques that have been developed to use in dependent demand situations. The lot-by-lot technique is consistent with the Just-in-Time production control philosophy that we will discuss later. An alternate method of scheduling item 301 to meet the requirements of item 201 is provided in Table II (d). Will this schedule work? YES, but it causes more WIP. Is this good or bad? It depends on the cost to set-up the production lines to produce item 301, and the cost to hold inventory of completed item 301's. If it cost more to set-up the production line than it does to hold inventory for a week; then once the production line is set-up, I need to build at least two weeks worth of demand for the item. The lot sizing technique that is depicted in Table II (d) is called Periodic Order Quantity. In this technique, I use information on set-up or ordering cost, and holding cost to determine how many weeks of production I should produce whenever I start producing an item. In the example, the set-up and holding cost were such that a 3 week period was the optimal.

As mentioned above, there are several techniques that can be used to determine the optimal lot size. The obvious question is, which is better? In simulated experiments at the University of Arkansas [3], they found one technique to be far superior to all others, one technique to be far inferior to all others, and all the other techniques to be equivalent. The superior technique was Periodic Order Quantity; the inferior technique was Lot-by-Lot.

<p style="text-align: center;"><b>TABLE III</b> <b>MRP Table for Item 302</b></p>									
ITEM: 302 (assuming POQ = 3 weeks)									
Period (aka: time bucket)	0	1 Feb 1	2	3	4	1 Mar 5	6	7	8
Gross Reqmt's		0	300	300	300	300	0	0	0
Scheduled Receipts		0	900	0	0	300	0	0	0
On hand	0	0	600	300	0	0	0	0	0
Plan'd Order Release	900	0	0	300	0	0	0	0	0

A final example of a MRP table is shown in Table III. This example is for item 302 that has a two week lead-time. Using a POQ = 3 weeks, notice that a planned order release of 900 occurred during period 0. When is period zero? It is the prior week. What does this schedule say? It is telling me that I must have work orders in progress for 900 item 302's. Otherwise, I will not meet my end item delivery schedule. This is identical to having projected the LOB two months into the future. However, with MRP, I am accomplishing this weekly.

Did the above calculations seem overwhelming? Well imagine that you work in a plant that builds 100 end items and each end item has 100 subassemblies, components, or raw materials that go into it. This would require MRP tables be built for  $100 \times 100 = 10,000$  items each week. This could get a little tiring. That is why computer systems are relied upon to build these schedules. Computers never tire of performing all these calculations.

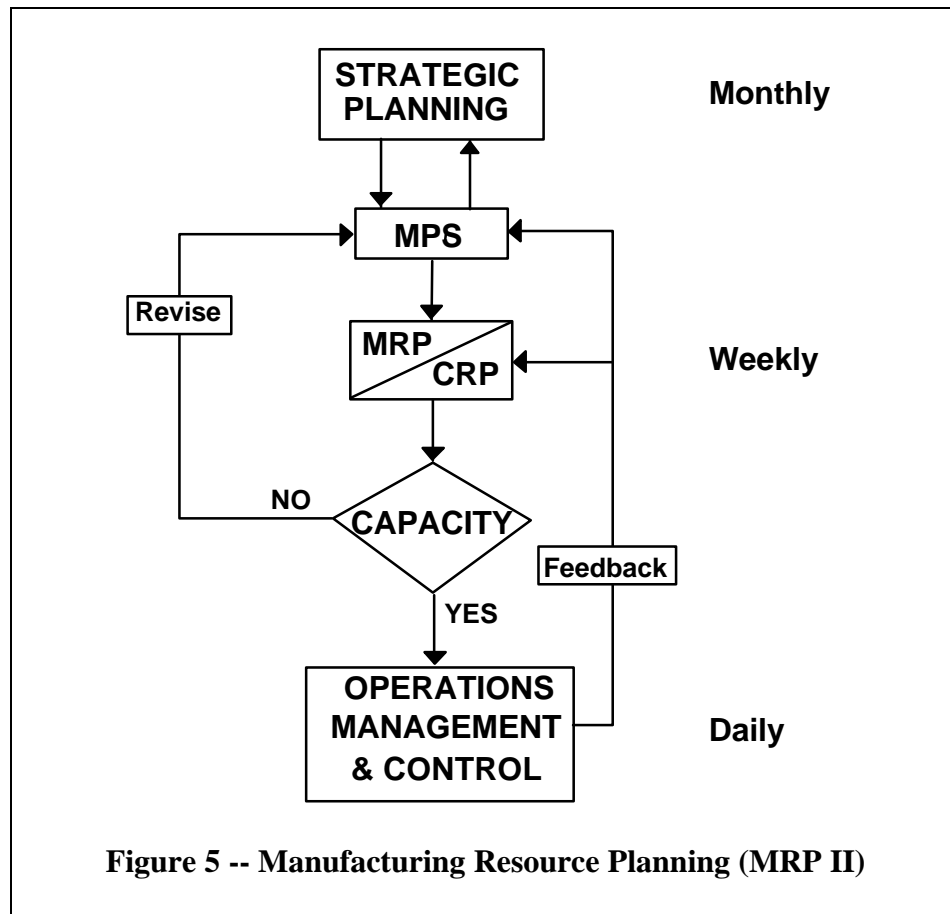
### Manufacturing Resource Planning (MRP II)

It should be easy to see that all the MRP schedules are driven by the Master Production Schedule (MPS). They all assume that the capacity to produce these items and meet the MPS exists. Most systems implemented today are not the simple MRP systems that we just discussed. But, they are MRP II systems, which is defined as:

*an integrated system which utilizes a set of decision rules to determine optimal shop loading (when, how much, and priorities) to accomplish the MPS within the capacity of the facility.*

Integration means that MRP II links together all the high level planning of the company (Marketing Plan, Financial Plan, and Production Plan) with the lower level systems required to meet these plans (MRP, MPS, Shop Floor Control, Purchasing, Inventory, etc.) This assures that all system elements are working toward the same goal of meeting customer demand. The decision rules are ways in which the MRP II system trades off planned production of one item for production of other items. An example of one of these decision rules is the choice of lot sizing technique, such as: Lot-by-Lot or POQ ordering.

The MRP II system must assure that the production facility is capable of accomplishing the MPS or all these plans can result in an inability to meet promised delivery dates. This is performed in an iterative manner as depicted in Figure 5. The company's strategic plans for the future are



translated into a MPS. MRP schedules are constructed to support this MPS. The next step is to perform Capacity Requirements Planning (CRP). This tells us what equipment, personnel, and materials we need to meet the MRP schedules. If we do not have this capacity, then the MPS and possibly the strategic plans must be revised. This process continues until our MRP schedules are consistent with the plant capacity. These schedules are then released to the departments that are responsible for performing the production and/or purchasing operations. These production operations continuously feed back actual accomplishment information to the MRP/MPS elements that allow the plans to be updated. This creates a truly closed loop manufacturing planning and execution system.

Question. In checking the plant capacity constraints to determine if the MRP schedules are feasible, do all operations & equipment in the plant have to be assessed? Hint. Have you read "The Goal"? Who is Herbie?

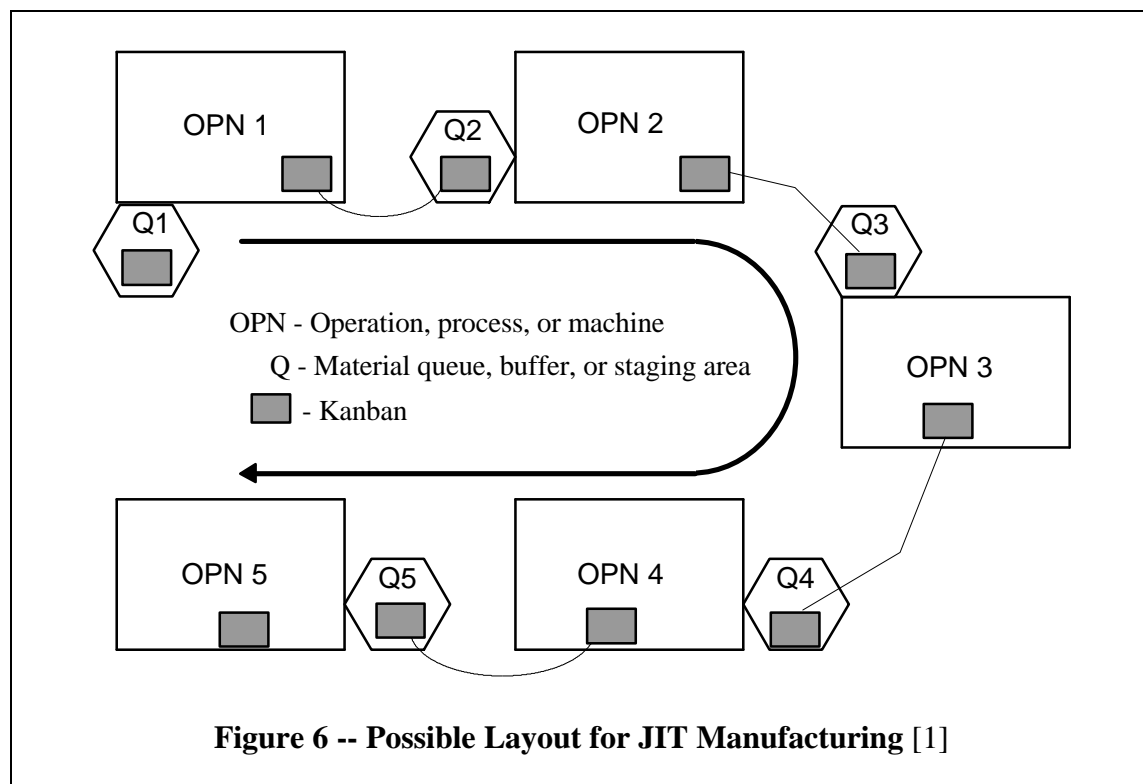
### **Just-In-Time (JIT) Production Management**

JIT is a philosophy of continuously eliminating waste and non-value added processes. Non-value added processes can take on numerous forms in manufacturing, such as: excess inventory, excess materials handling, rejected parts, and excessively long set-up times. A JIT program involves multi-faceted themes that could take volumes to discuss. Therefore, we will limit our discussion to only three themes that are most pertinent to the course at hand. These are JIT Quality Improvement, JIT Materials Management, and JIT Purchasing.

Figure 6 gives a sample layout for a JIT facility. Because this facility may produce numerous products, we cannot assume that parts flow is sequential from operation 1 to operation 2, etc. Parts flow may occur between any two operations. Regardless of the sequence of operations, one operation will control the rate at which this facility can produce a particular product (i.e. the bottleneck). With this in mind, let's discuss the three themes of JIT.

The JIT Quality theme puts the responsibility for quality in the hands of the worker. The worker is responsible for assuring that the parts submitted to subsequent operations will meet the need of these operations and the final customer. Any defects must become immediately visible. This has led to the well publicized system whereby the production line may be stopped while the source of defects is discovered and corrected. This minimizes the number of defects passed on to subsequent operations. However, this area of quality improvement only attacks special causes of defects and is only a portion of the JIT quality theme. To assure continuous improvement in quality, the worker must be equipped with statistical tools such as Statistical Process Control and Design of Experiments. These tools allow the worker to continuously improve quality by reducing common causes of variability in the product.

The JIT material management theme is depicted in Figure 6. Each of the buffers represents WIP. All agree that the amount of WIP should be minimized. To insure a minimal amount of WIP, a Kanban approach is utilized. A Kanban is simply a finite amount of storage. It may be a tote bin, pallet, conveyor, storage rack, etc. Let's take a look at how the Kanban approach works. Assume Operation 1 feeds parts to Operation 2. Operation 1 would continue to produce parts until it has filled the Kanban. Once the Kanban is full, it would temporarily cease production. When the Kanban at Operation 2 is close to empty, Operation 2 would signal Operation 1 to deliver another Kanban. This would empty the Kanban at Operation 1 allowing this operation to produce. This



causes the Kanban to be an upper limit on the amount of WIP between the two operations. There are differing opinions on how to size the Kanban. Some think that a size of one is the best. Lets investigate this. If material flow is sequential throughout Figure 6, and the Kanban size is only one; then if any operation stops, all operations must stop. This could lead to excessive amount of idle time at all operations. Since idle time is a non-value added operation, it is counter to the JIT philosophy. In addition, this philosophy (i.e. Kanban of one) ignores the cost of operation setup. Recall the EOQ model on page 4. In all lot sizing techniques, the holding cost is balanced with the setup/ordering cost to achieve a minimal total cost. If the Kanban is one, then the holding cost is virtually zero. But, the setup/ordering cost skyrockets, creating a non-optimal cost situation.

In today's manufacturing environment, we have available many techniques that can be used to determine the expected downtime of an operation. Armed with downtime data, holding cost information, and order/setup cost, we can create analytical or simulated models of the system to determine the optimal size of each Kanban that will generate both minimal downtime and minimal WIP in the system.

In light of the Kanban operation above, some believe that whenever a operator has filled the Kanban, that operator should remain idle until the Kanban is emptied. In repetitive manufacturing, it is impossible to balance operations such that each operation along a production line takes approximately the same amount of time. This ultimately leads to bottleneck operations. If operators remain idle until their Kanban is emptied, some operators may work only a small portion of the workday. A better approach in JIT is to allow idle operators to perform other productive work, such as assisting slower operations in their vicinity. Of course, this requires that unions accept the concept of cross-training operators.

The final theme of JIT is JIT Purchasing. In today's manufacturing, larger and larger percentages of manufactured products are outsourced. Under JIT, companies attempt to create long range commitments with their suppliers. In addition, they provide these suppliers with small lot sizes and frequent deliveries. This is the expansion of the Kanban approach to the supplier network. This concept requires that suppliers be located close to the plant. In Japan, this was relatively easy to implement because all of Japan is smaller than the state of California. In the United States, this has been a continual problem. But, it is one that we must continue to address in order to remain competitive in the World Marketplace.

## **JIT and MRP II**

Because so much has been written about MRP and JIT individually, many believe that they are opposing systems. Some have gone so far as to say that if you are implementing JIT, you must remove any type of MRP system you may have been using. This is totally false. In studying JIT systems in Japan, Goodrich [2] has found that most of them (except for mass production lines) utilize a materials management system similar to the American MRP systems. In addition, we must remember that the objective of both systems is the same. The goal of JIT is to continuously improve all areas of the company, including the inventory position. However, JIT requires techniques and data systems to assist in achieving this goal. MRP II is a proven system to provide this information. MRP II will:

- identify WIP cost drivers,
- insure proper Kanban size,
- insure incoming materials availability,

- prevent stockouts,
- accommodate capacity constraints, and
- track customer orders.

The MRP II system should not be used alone. Alone, it will insure and optimal level of WIP, but can only perpetuate the status quo; it will not improve the system. But, when linked with the JIT philosophy, it can continuously identify areas for improvement. Basically, in repetitive manufacturing, the two should always be implemented together, and never alone.

## References

- [1] Cubberly, W.H., and Bakerjian, R (editors), Tool and Manufacturing Engineers Handbook, Desk Editiono, SME, Dearborn, Mi, 1989.
- [2] Goodrich, T., "JIT and MRP Can Work Together," Automation, April 1989.
- [3] Malstron, E.M., Class Notes, Dept of Industrial Engineering, University of Arkansas, Fayetteville, Ar.
- [4] Tersine, R.J., Principles of Inventory and Materials Management, 3rd edition, North-Holland, New York, N.Y., 1988.